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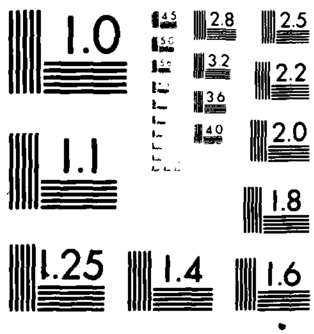

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Volume II

A BIBLIOGRAPHY OF RECENT DEVELOPMENTS IN UNSTEADY TRANSONIC FLOW

Volume II

C. J. Borland

THE BOEING COMPANY
P.O. Box 3999
Seattle, Washington 98124

June 1980

Final Report for Period 15 November 1978 to November 1979

Approved for public release; distribution unlimited

FLIGHT DYNAMICS LABORATORY
AIR FORCE WIRHGT AERONAUTICAL LABORATORIES
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This technical report has been reviewed and is approved for publication.

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Analytical	Numerical	Flutter	W[illegible]
Computational	Nonlinear	Oscillating	Finit[illegible] ifference

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A bibliography of recent developments in unsteady transonic flow is presented. Papers have been divided into survey, experimental, and theoretical classifications. Publications have been reviewed, listed, and summarized in tabular form. Primary emphasis has been placed on numerical solution of unsteady transonic flow problems.

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FOREWORD

This report was prepared by Boeing Military Airplane Company, The Boeing Company, Seattle, Washington, for the Analysis and Optimization Branch of the Structures and Dynamics Division, Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Boeing conducted the work under Contract F33615-78-C-3201, "Transonic Unsteady Aerodynamics for Aeroelastic Applications" under Project 2401, and Task 02. Dr. James Olsen is the Project Engineer.

The updated bibliography was prepared during the period November 15, 1978 to November 15, 1979.

The Project Manager for Boeing was Dr. H. Yoshihara and the Principal Investigator was C. J. Borland.

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A Bibliography of

Recent Developments in Unsteady Transonic Flow

SECTION I INTRODUCTION

This report is the first yearly update of the bibliography published as Volume I. Papers and reports which have appeared or been uncovered during the latter part of 1978 and during 1979 have been reviewed.

Published works in the field of unsteady transonic flow which have become available during the past year have generally fallen into three categories, which seem to reflect a changing emphasis in the field:

a) development of simplified methods, some based on extensions of linear theory, whose primary purpose is to provide insight into the nature of unsteady transonic flow, and which can be run economically;

b) extension and applications of existing methods, based on previously published works, in particular, several papers covering applications to aeroelastic problems have appeared;

c) experimental studies aimed specifically at obtaining unsteady pressure data for correlation of the results of numerical solutions.

In addition to these, some new developments in numerical solutions have become available. In particular, two important papers on solution of the full potential equation for two dimensional unsteady transonic flow have been published.

The following sections of this document consist of the detailed reviews, a summary chart, and an alphabetized list of references, including author, title, source, and date. No accession numbers were available since references were selected from original material, rather than from a data base search, as in Volume I of this report.

SECTION II DETAILED REVIEWS

In this section, the recently published papers relating to developments in unsteady transonic flow and aeroelastic applications are reviewed in some detail. As in the previous volume, papers are divided into three basic categories, survey, theoretical, or experimental.

2.1 Survey Papers

Chapman, D. R.: Computational Aerodynamics Development and Outlook; AIAA Paper 79-0129, 17th Aerospace Sciences Meeting, New Orleans, LA, January 15-17, 1979.

- 29 pages, 25 figures, 150 references
- Discusses state of the art in computational fluid mechanics. Particular emphasis on numerical solutions of the Navier-Stokes equations. Transonic flow examples for wing body combinations, unsteady separated flow, aileron buzz.

2.2 Theoretical Papers

Ashley, H.: On the Role of Shocks in the "Sub-Transonic" Flutter Phenomenon; AIAA Paper 79-0765, 20th Structures, Structural Dynamics and Materials Conference, St. Louis, MO, April 4-6, 1979

- 11 pages, 20 figures, 34 references
- Basic Equations: 2-D Linear Unsteady plus "Shock Doublet"
- Boundary Conditions: Linearized Airfoil BC for plunging and pitching
- Examples: TF-8A Supercritical Airfoil; 18 percent biconvex, NACA 64A006
- Remarks: Demonstrates qualitative effect of presence and motion of shocks, through a simplified model, on flutter.

Bennett, R. M., and Bland, S. R.: An Exploratory Study of a Finite Difference Method for Calculating Unsteady Transonic Potential Flow; NASA Technical Memo 80105, June 1979

- 20 pages, 15 figures, 12 references
- Basic Equations: 2-D Unsteady Full Potential
- Coordinate Systems: Stretched Cartesian
- No. Mesh Points: 57 x 57
- Boundary Conditions: Exact at mean position
- Numerical Algorithm: Semi-implicit
- Computation Times: 500-2500 CP seconds (Cyber 175)
- Examples: NACA 64A006 M=.5, .875
- Remarks: Application of Isogai full potential code. Shows possible numerical resonances at discrete frequencies

Chipman, R., Waters, C., and MacKenzie, D.: Numerical Computation of Aeroelastically Corrected Transonic Loads; AIAA Paper 79-0766; 20th Structures, Structural Dynamics and Materials Conference, St. Louis, Mo., April 4-6, 1979.

- 7 pages, 16 figures, 8 references
- Basic Equations: 3-D Steady Small Disturbance plus linear aeroelastic
- Coordinate Systems: Stretched, swept Cartesian
- No. Mesh Points: 60 x 30 x 20
- Boundary Conditions: Linearized surface BC, modified for aeroelastic deformation
- Numerical Algorithm: Line overrelaxation
- Examples: Supercritical transport wing
- Remarks: First known attempt to couple 3-D CFD solution with aeroelastic solution. Demonstrates feasibility of performing aeroelastic solutions for essentially same cost as rigid solutions.

Chipman, R. and Jameson, A.: Fully Conservative Numerical Solutions for Unsteady Irrotational Transonic Flow about Airfoils; AIAA Paper 79-1555, 12th Fluid and Plasma Dynamics Conference, Williamsburg, VA, July 23-25, 1979.

- 9 pages, 6 figures, 19 references
- Basic Equations: 2-D Unsteady Irrotational
- Coordinate Systems: Sheared Cartesian
- No. Mesh Points: 3000-5000
- Boundary Conditions: Exact inviscid on time-dependent airfoil shape
- Numerical Algorithm: Explicit predictor-corrector on primitive variables
- Examples: Circular arc airfoil, thickening and with oscillating flap, NACA 64A006, (steady only)

Goorjian, P. M.: Computations of Unsteady Transonic Flow governed by the Conservative Full Potential Equation Using an Alternating Direction Implicit Algorithm; NASA CR-152274, June 1979.

- 45 pages, 9 figures, 28 references
- Basic Equations: 2-D Unsteady Full Potential
- Coordinate Systems: Sheared Cartesian
- No. Mesh Points: 151 x 41 (Symmetric)
- Boundary Conditions: Exact inviscid on time dependent airfoil shape
- Numerical Algorithm: Fully Conservative ADI
- Examples: Circular arc thickening airfoil
- Remarks: Compares results of full potential and small disturbance (LTRAN2) calculations

Houwink, R., and Van der Vooren, J.: Results on an Improved Version of LTRAN2 for Computing Unsteady Airloads on Airfoils Oscillating in Transonic Flow; AIAA Paper 79-1553, 12th Fluid and Plasma Dynamics Conference, Williamsburg, VA, July 23-28, 1979.

- 7 pages, 7 figures, 9 references

o	Basic Equations:	2-D Unsteady (low frequency) small disturbance
o	Coordinate Systems:	Stretched Cartesian
o	Boundary Conditions:	Small disturbance on oscillating airfoil, flap
o	Numerical Algorithm:	Time Marching ADI
o	Examples:	Flatplate, NACA 64A006
o	Remarks:	Extends LTRAN2 method of Ballhaus and Goorjian to include time dependent terms in boundary conditions and pressure coefficient expression.

McGrew, J. A., Giesing, J. P., et al.: Supercritical Wing Flutter, AFFDL TR 78-37, March 1978.

- 221 pages, 90 figures, 17 references

o	Basic Equations:	2-D and 3-D Unsteady Linearized Small Disturbance
o	Coordinate Systems:	Cartisian
o	No. Mesh Points:	16 x 8 panels (typical)
o	Boundary Conditions:	Small Disturbance
o	Numerical Algorithm:	Doublet lattice with transonic weighting factors
o	Examples:	TF-8A Supercritical wing flutter model, YC-15 flutter model
o	Remarks:	Attempted to modify linear lifting surface theory with steady and unsteady weighting factor to account for transonic effects. Corrections based on disturbances in nonuniform flow fields are investigated.

Pi, W. S., Kelly, P. D., and Liu, D. D.: A Transonic Doublet Lattice Method for Unsteady Flow Calculations; AIAA Paper 79-0078, 17th Aerospace Sciences Meeting, New Orleans, LA, January 15-17, 1979

- 9 pages, 10 figures, 21 references
- Basic Equations: 2-D and 3-D Linearized unsteady small disturbance
- Coordinate Systems: Cartesian
- No. Mesh Points: 100 panels
- Boundary Conditions: Linearized
- Numerical Algorithm: Doublet Lattice Method modified for transonic effects
- Computation Times: 3 Min CPU (IBM370)
- Examples: NACA 64A006 airfoil with .25c oscillating flap; AR=5 rectangular wing

Rizzetta, D. P.: Time Dependent Response of a Two-Dimensional Airfoil in Transonic Flow; J. of AIAA, Vol 17, No. 1, January 1979.

- 7 pages, 10 figures, 23 references
- Basic Equations: 2-D unsteady (low frequency) small disturbance
- Coordinate Systems: Stretched Cartesian
- No. Mesh Points: 99 x 79
- Boundary Conditions: Small disturbance on airfoil, coupled with aeroelastic solution
- Numerical Algorithm: ADI plus Adams-Moulton predictor-corrector
- Examples: NACA 64A010, M=.72, with various aeroelastic parameters
- Remarks: Uses LTRAN2 with coupled aeroelastic solution to predict behavior of three-degree of freedom system and sensitivity to system parameters

Rizzetta, D.P., Rubbert, P., and Yoshihara, H.: Computation of Unsteady Transonic Flows with Boundary Layer Displacement Effects, Boeing Document D180-25071-1, February, 1979.

- o 11 pages, 5 figures, 4 references
- o Basic Equations: 2-D Unsteady small disturbance
- o Coordinate Systems: Stretched Cartesian
- o No. Mesh Points: 99 x 79
- o Boundary Conditions: Small disturbance on oscillating airfoil plus viscous ramp correction
- o Numerical Algorithm: ADI
- o Examples: NACA 64A 010, M=.8, pitch oscillation
- o Remarks: Uses LTRAN2 method plus viscous ramp approximation to demonstrate effects of including shock-boundary layer interaction on unsteady flow

Rizzetta, D. P., and Chin, W. C.: Effect of Frequency in Unsteady Transonic Flow, J. of AIAA, Vol 17, No. 7, July 1979

- o 3 pages, 3 figures, 4 references
- o Basic Equations: 2-D Unsteady small distrubance
- o Coordinate Systems: Stretched Cartesian
- o No. Mesh Points: 113 x 97
- o Boundary Conditions: Small disturbance on oscillating airfoil and oscillating flap, and impulsive angle of attack
- o Numerical Algorithm: ADI
- o Examples: NACA 64A010 M=.82
- o Remarks: Extends LTRAN2 method to high frequency by including high frequency terms in potential equation, boundary condition, and pressure coefficient expression.

Steger, J. L., and Bailey, H. E.: Calculation of Transonic Aileron Buzz; AIAA Paper 79-0137, 17th Aerospace Sciences Meeting, New Orleans, LA, January 15-17, 1979.

- 12 pages, 16 figures, 15 references
- Basic Equations: 2-D Thin-Layer Navier-Stokes
- Coordinate Systems: Conformal time-dependent "O-type" and C-type" grids
- Boundary Conditions: Exact no-slip BC on fixed airfoil with free-floating flap
- Numerical Algorithm: Approximate factored implicit
- Examples: NACA 65 - 213 with .25C flap M=.79 to .83
- Remarks: Comparison of fully viscous CFD computation with aileron buzz wind tunnel data on 3-D wing. Successfully predicts limit cycle behavior of free aileron. Inviscid calculation shows instability but not limit cycle.

Williams, M. H.: Unsteady Thin Airfoil Theory for Transonic Flows with Embedded Shocks; AIAA Paper 79-0204, 17th Aerospace Sciences Meeting, New Orleans, LA, January 15-17, 1979.

- 11 pages, 12 figures, 19 references
- Basic Equations: 2-D Linear Unsteady plus shock disconuity
- Boundary Conditions: Linearized airfoil and oscillating flap.
- Examples: NACA 64A006 with oscillating flap.
- Remarks: Uses experimental data to determine shock strength and location, then modifies linearized airfoil theory to include shock effect

Williams, M. H.: Unsteady Airloads in Supercritical Transonic Flows; AIAA Paper 79-0767, 20th Structures, Structural Dynamics and Materials Conference, St. Lous, MO, April 4-6, 1979

- o 7 pages, 13 figures, 3 references
- o Basic Equations: 2-D Linear Unsteady plus Shock Disconuities
- o Boundary Conditions: Linearized steady and oscillating airfoil, oscillating flap
- o Examples: NACA 64A006 with oscillating flap NACA 64A010 oscillating in pitch
- o Remarks: Uses method of earlier paper. Compares results with experimental data and Euler equation results (Magnus).

Williams, M. H.: Linearization of Unsteady Transonic Flows Containing Shocks; J. of AIAA, Vol. 17, No. 4, April, 1979.

- o 4 pages, 12 references
- o Basic Equations: 3-D Linear Unsteady
- o Boundary Conditions: Linearized Airfoil
- o Remarks: Theoretical development of linearized unsteady method which has been specialized to 2-D in previous papers

Yang, T. Y., Striz, A. G., and Guruswamy, P.: Flutter Analysis of Two-Dimensional and Two-Degree-of-Freedom Airfoils in Small Distrubance Unsteady Transonic Flow, AFFDL TR 78-202, December, 1978

- 103 pages, 41 figures, 38 references

o Basic Equations:	2-D unsteady small disturbance plus aeroelastic equation
o Coordinate Systems:	Stretched Cartesian
o No. Mesh Points:	35 x 38; 59 x 60; 79 x 99
o Boundary Conditions:	Linearized, oscillating airfoil
o Numerical Algorithm:	Relaxation (UTRANS) and Time Marching ADI (LTRAN2)
o Examples:	NACA 64A006 M=.7, .85, .9, .95 NACA 64A010 M=.72, .76, .80, .94
o Remarks:	Demonstrates two degree of freedom airfoil flutter calculations using harmonic results from relaxation method (UTRANS) and indicial results from time marching method (LTRAN2)

Yang, T. Y., Guruswamy, P., and Striz, A. G.: Aeroelastic Response Analysis of Two Dimensional, Single and Two Degree of Freedom Airfoils in Low Frequency, Small Disturbance, Unsteady Transonic Flow; AFFDL TR-79-3077, June 1979

- 55 pages, 18 figures, 13 references

o Basic Equations:	2-D unsteady small disturbance and aeroelastic equations
o Coordinate Systems:	Stretched Cartesian
o No. Mesh Points:	79 x 99
o Boundary Conditions:	Linearized, oscillating airfoil
o Numerical Algorithm:	Time Marching ADI
o Examples:	Flat Plate M=.7 NACA 64A006 M-.85
o Remarks:	Demonstrates coupled time-marching aeroelastic integration solution for dynamic response of two degree of freedom airfoils

2.3 Experimental Papers

Davis, J., and Petrie, S. L.: Unsteady Pressures on an NACA 64A010 Airfoil: Experimental and Theoretical Results; AIAA Paper 79-0330, 17th Aerospace Sciences Meeting, New Orleans, LA, January 15-17, 1979.

- o 10 pages, 18 figures, 13 references
- o Facility: Ohio State University Transonic Airfoil Wind Tunnel
- o Test Section and Wall Conditions: 6" x 12" open circuit, slotted wall; independent plenum
- o Model: NACA 64A010 airfoil, 6" chord
- o Mach Number: .80
- o Motion: Sinusoidal Oscillation
- o Frequencies: 110 Hz
- o Measurements: Steady and unsteady surface pressures
- o Remarks: Comparisons with Euler (Magnus) and small disturbance (Traci) calculations and NASA/Ames Data

Davis, S. S. and Malcolm, G. N.: Experiments in Unsteady Transonic Flow, AIAA Paper 79-0769, 20th Structures, Structural Dynamics, and Materials Conference, St. Louis, MO. April 4-6, 1979

- o 17 pages, 26 figures, 26 references
- o Facility: NASA Ames 11 x 11 ft Transonic Wind Tunnel
- o Test Section & Wall: 11 ft x 4.5 ft between splitter plates, slotted walls
- o Model: NACA 64A010 airfoil, .5m Chord
- o Mach Number: .5, .8
- o Motion Plunge, Pitch (axis variable)
- o Frequencies: Up to 60 Hz
- o Measurement: Steady and unsteady pressures
- o Remarks: Extensive data for comparison with calculations; effects of mean angle of attack

Roos, F. W.: Some Features of the Unsteady Pressure Field in Transonic Airfoil Buffeting; AIAA Paper 79-0351, 17th Aerospace Sciences Meeting, New Orlean, LA, January 13-17, 1979

- 10 pages, 21 figures, 17 references
- Facility: NASA Ames 2 x 2 foot Transonic Wind Tunnel
- Test Section: 61 cm wide
- Models: NACA 0012, Whitcomb Supercritical airfoil, 15 cm chord
- Mach No.: .64 to .90
- Motion: Steady
- Measurements: Steady and unsteady pressures due to buffeting

Tijdeman, H., et al.: Transonic Wind Tunnel Tests on an Oscillating Wing with External Stores, Part I: General Description; Part II: The Clean Wing; Part III: The Wing with Tipstore; Part IV: The Wing with Underwing Stores; AFFDL TR 78-194, Parts I-IV, 1979.

- approximately 300 pages
- Facility: NLR High Speed Tunnel
- Test Section and Wall Condition: Slotted walls
- Model: F-5 wing NACA 65A-004.8 airfoil, AR=1.5 wall mounted, with external stores
- Mach number: .6 to 1.35
- Motion: Up to 40 Hz
- Measurements: Steady and unsteady pressures
- Remarks: Extensive unsteady pressure data for a variety of configurations

Section III. Summary Chart

Author (date)	Type			Equations					Time-dependence		Geometry				Solution method					Data			
	Survey	Theoretical	Experimental	Navier-Stokes	Euler	Full potential	Small-disturbance	Linear	Steady	Unsteady	Airfoils	Control Surface	Wings	Wing-body	Relaxation	Time-marching	Finite element	Frequency expansion	Linear	Pressures	Forces, moments	Flutter	Wall effects
Ashley (1979)		●						●		●	●								●			●	
Bennett (1979)		●				●				●						●				●	●		
Chapman (1979)	●																						
Chipman (1979a)		●					●		●				●		●					●	●		
Chipman (1979b)		●				●				●	●					●				●			
Davis, J. (1979)			●							●	●									●	●		
Davis, S. (1979)			●						●	●	●									●	●		
Goorjian (1979)		●				●				●	●					●				●			
Houwink (1979)		●					●			●	●					●				●			
McGrew (1978)		●						●		●			●						●	●	●	●	
Pi (1979)		●						●		●			●						●	●		●	
Rizzetta (1979a)		●					●			●	●					●				●	●		
Rizzetta (1979b)		●					●			●	●					●				●	●		
Rizzetta (1979c)		●					●			●	●					●				●	●		
Roos (1979)			●							●	●									●			
Steger (1979)		●		●						●	●	●				●				●	●		
Tijdeman (1979)			●							●			●							●	●		
Williams (1979a)		●						●		●	●	●							●	●			
Williams (1979b)		●						●		●	●	●							●	●			
Williams (1979c)		●						●		●			●						●				
Yang (1978)		●					●			●	●				●	●				●	●	●	
Yang (1979)		●					●			●	●					●				●	●	●	

SECTION IV REFERENCE LIST

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